AD NUMBER
AD487030
LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; AUG 1966. Other requests shall be referred to Arnold Engineering Development Center, Arnold AFS, TN. This document contains export-controlled technical data.

AUTHORITY

AEDC ltr, 23 Jan 1975

DYNAMIC STABILITY TESTS ON THE
SNAP-27 FUEL CASK CONFIGURATION
AT MACH NUMBERS 6 AND 10

B. L. Uselton

ARO, Inc.

August 1966

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

DYNAMIC STABILITY TESTS ON THE SNAP-27 FUEL CASK CONFIGURATION AT MACH NUMBERS 6 AND 10

B. L. Uselton

ARO, Inc.

This document has been approved for public release its distribution is unlimited.

FOREWORD

The work reported herein was done at the request of the Atomic Energy Commission (AEC) for the General Electric Missile and Space Division (GE-MSD) under AEC Activity No. 04.30-01-41.3.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted under ARO Project No. VT1674 on April 14 and May 25, 1966. The manuscript was submitted for publication on July 20, 1966.

This technical report has been reviewed and is approved.

Donald E. Beitsch   Leonard T. Glaser
Major, USAF   Colonel, USAF
AF Representative, VKF   Director of Test
Directorate of Test

ABSTRACT

Tests were conducted in the 40-in. supersonic wind tunnel and the 50-in. Mach 10 wind tunnel (Tunnels A and C) of the von Kármán Gas Dynamics Facility to determine the dynamic stability characteristics of the SNAP-27 fuel cask configuration. These tests were conducted at Mach numbers 6 and 10 using the forced oscillation technique. Data were obtained at angles of attack from 0 to 14 deg for Reynolds numbers, based on centerbody diameter, ranging from 0.19 x 10^6 to 1.80 x 10^6.

CONTENTS

ILLUSTRATIONS

TABLE

NOMENCLATURE

A	Reference area, based on centerbody diameter, 0.0873 ft^2
C_m	Pitching-moment coefficient, pitching moment$/q_\infty Ad$
C_{m_q}	$\partial C_m / \partial (qd/2V_\infty)$ ⎱ Damping-in-pitch derivatives, 1/radian
$C_{m_{\dot{\alpha}}}$	$\partial C_m / \partial (\dot{\alpha} d/2V_\infty)$ ⎰
C_{m_α}	Local slope of pitching-moment curve, 1/radian
d	Reference length, centerbody diameter, 0.333 ft
f	Frequency of oscillation, cycles/sec
I	Model mass moment of inertia about the pivot axis, slug-ft^2
ℓ	Model length, in.
M_θ	Angular restoring-moment parameter, ft-lb/radian
$M_{\dot{\theta}}$	Angular viscous-damping-moment parameter, ft-lb-sec/radian
M_∞	Free-stream nominal Mach number
q	Pitching velocity, radians/sec
q_∞	Free-stream dynamic pressure, lb/ft^2
Re_d	Reynolds number based on centerbody diameter
T	Input torque, ft-lb
t	Time, sec
V_∞	Free-stream velocity, ft/sec
x_{cg}	Distance from model nose to pivot axis, in.
α	Angle of attack, radians or deg
$\dot{\alpha}$	Time rate of change of angle of attack, radians/sec
θ	Angular displacement, radians or deg
$\dot{\theta}$	Angular velocity, radians/sec
$\ddot{\theta}$	Angular acceleration, radians/sec^2
ω	Angular frequency, radians/sec
$\omega d/2V_\infty$	Reduced frequency parameter, radians

SUBSCRIPTS

a	Aerodynamic
o	Maximum conditions
v	Vacuum conditions
w	Wind-on conditions

SECTION I
INTRODUCTION

The SNAP-27 power generator, stored externally on the Lunar Excursion Module (LEM), is to be landed on the moon and assembled by the astronauts. In the event of an aborted mission, the SNAP-27 fuel cask will be separated from LEM and achieve an earth orbit. The fuel cask must, therefore, have the capability to re-enter the earth's atmosphere and to impact undamaged to avoid radioactive contamination of the atmosphere.

In support of an aerodynamic design program conducted by GE-MSD, static force, pressure, and dynamic stability tests were conducted at AEDC at supersonic and hypersonic speeds. The dynamic stability tests described in this report were conducted on the SNAP-27 fuel cask configuration at Mach numbers 6 and 10 at Reynolds numbers, based on the model centerbody diameter, ranging from 0.19×10^6 to 1.80×10^6 for an angle-of-attack range from 0 to 14 deg. The tests, as outlined in Table I, were conducted using a small amplitude (± 3-deg), forced oscillation balance.

SECTION II
APPARATUS

2.1 WIND TUNNELS

The 40-in. supersonic and 50-in. Mach 10 tunnels (Gas Dynamic Wind Tunnels, Supersonic (A) and Hypersonic (C)) of the von Kármán Gas Dynamics Facility (VKF) are continuous, closed-circuit, variable density wind tunnels. Tunnel A has a flexible-plate-type nozzle which is automatically driven to produce Mach numbers from 1.5 to 6. The tunnel has a 40- by 40-in. test section and operates at maximum stagnation pressures from about 29 to 200 psia at $M_\infty = 1.5$ to 6 and at stagnation temperatures up to 300°F ($M_\infty = 6$). Minimum operating pressures are about one-tenth of the maximum.

Tunnel C has a 50-in.-diam contoured, axisymmetric, Mach 10 nozzle and operates at stagnation pressures from 200 to 2000 psia and at stagnation temperatures up to about 1450°F. The model support is capable of being retracted into a test section tank which can be sealed from the airflow for model changes. A description of the tunnels and airflow calibration information may be found in Ref. 1.

2.2 FORCED OSCILLATION BALANCE

The small amplitude (±3-deg), forced oscillation balance system used in the test program is a one-degree-of-freedom oscillatory system incorporating a cross-flexure pivot. The balance (Fig. 1) is forced to oscillate by an electromagnetic shaker motor located in the aft portion of the sting. The angular displacement of the model is measured by a strain-gage bridge mounted on a cross flexure, and the input torque to the system is measured by a strain-gage bridge mounted at the minimum cross-sectional area of the torque beam. The forcing system is equipped with a feedback control network, as described in Ref. 2, to provide positive amplitude control for testing either dynamically stable or unstable configurations.

Because of the high stagnation temperatures encountered in Tunnel C, the sting assembly is water cooled. The balance is cooled by air which is directed on the model bulkhead while damping measurements are not being made.

2.3 MODEL

The model, shown in Fig. 2, was supplied by the General Electric Company and was constructed of stainless steel. Provisions were made to add ballast fore and aft to locate the model center of gravity exactly at the balance pivot axis. The model geometry is shown in Fig. 3.

SECTION III
PROCEDURE

The motion of the one-degree-of-freedom, forced oscillation system may be defined by the equation

$$I\ddot{\theta} - M_{\dot{\theta}}\dot{\theta} - M_{\theta}\theta = T\cos\omega t$$

Damping-in-pitch data were obtained throughout the tests at the undamped natural frequency of the model balance system, whereby the inertia term $(I\ddot{\theta})$ exactly balances the restoring-moment term $(M_{\theta}\theta)$; thus, the forcing torque is precisely equal to the damping torque of the system for constant amplitude motion. The method for computing the dimensionless damping-in-pitch derivatives for the constant amplitude, forced oscillation tests is indicated by the following expressions:

$$-M\dot{\theta}\dot{\theta} = T \cos \omega t \text{ (at the undamped natural frequency}$$
$$\text{of the system)}$$

$$M\dot{\theta} = -\Gamma/\theta_o \omega$$

$$M\dot{\theta}_a = M\dot{\theta}_w - M\dot{\theta}_v (\omega_v/\omega_w)$$

$$C_{m_q} + C_{m\dot{\alpha}} = M\dot{\theta}_a (2V_\infty / q_\infty Ad^2)$$

The expression for obtaining the aerodynamic viscous-damping-moment parameter ($M\dot{\theta}_a$) is based on the premise that the structural damping of a cross-flexure pivot varies inversely with the frequency of oscillation (Ref. 3).

The change in model oscillation frequency from the wind-off to the wind-on condition may be used to obtain the static stability derivative (C_{m_α}) by the following expressions:

$$\omega = \sqrt{-M_\theta/I}$$

$$M_{\theta_a} = M_{\theta_w} - M_{\theta_v}$$

$$M_{\theta_a} = M_{\theta_v} [(f_w/f_v)^2 - 1]$$

$$C_{m_\alpha} = M_{\theta_a}/q_\infty Ad$$

SECTION IV
PRECISION OF MEASUREMENTS

The balance was calibrated before and after the tests, and check calibrations were made before and after each run. In addition, structural damping values were obtained at vacuum conditions before the tunnel entry to evaluate the still air damping contribution. The estimated maximum deviation in C_{m_α} is ±0.6 and in $C_{m_q} + C_{m\dot{\alpha}}$ is ±6.0.

SECTION V
RESULTS

Figure 4 shows the effect of angle of attack on the damping-in-pitch derivatives ($C_{m_q} + C_{m\dot{\alpha}}$) and the static stability derivative (C_{m_α}) at Mach numbers 6 and 10. The Mach 6 damping data (Fig. 4a) indicate the model to be stable at all conditions tested and the damping to be a nonlinear function of angle of attack. The local slope of the pitching-moment curve (C_{m_α}) at Mach 6 is shown to be a minimum at $\alpha \approx 8$ deg

(Fig. 4a) for Reynolds numbers 0.35 x 10^6 and 0.73 x 10^6. The Mach 10 damping data (Fig. 4b) show the model to be stable at the trim angle (α = 0) at all Reynolds numbers tested. Increasing angle of attack (α = 0 to α = 5 deg) decreases stability, and the model is unstable at α = 5 deg (Re$_d$ = 0.34 x 10^6). The model is stable, however, at angles of attack of 8 deg and above. The data obtained at Re$_d$ = 0.58 x 10^6 showed the model to be unstable at α =6 deg; however, the level of the instability was not obtained. The local values of C_{m_α} obtained at M_∞ = 10 (Fig. 4b) are essentially invariant with angle of attack except at angles of attack of about 5 or 6 deg (negative damping results) where a higher level of C_{m_α} was obtained.

The data obtained at α = 0 are shown in Fig. 5 as a function of Reynolds number. The damping derivatives are a maximum at a Reynolds number of about 0.6 x 10^6 for both Mach numbers tested, and the Mach 10 data are at a higher level than the Mach 6 data at comparable Reynolds numbers. The static stability derivative for both Mach numbers decreases with increasing Reynolds number with the Mach 6 data showing a higher level than the Mach 10 data.

REFERENCES

1. Test Facilities Handbook (5th Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, July 1963.

2. Welsh, C. J., Hance, Q. P., and Ward, L. K. "A Forced-Oscillation Balance System for the von Kármán Gas Dynamics Facility 40- by 40-Inch Supersonic Tunnel." AEDC-TDR-61-63 (AD 257380), May 1961.

3. Welsh, C. J. and Ward, L. K. "Structural Damping in Dynamic Stability Testing." AEDC-TR-59-5 (AD 208776), February 1959.
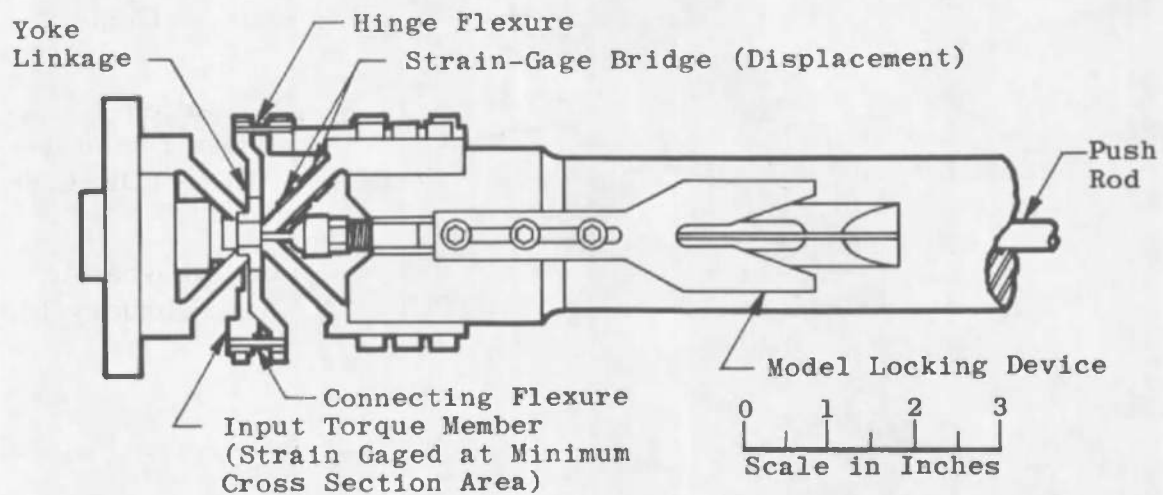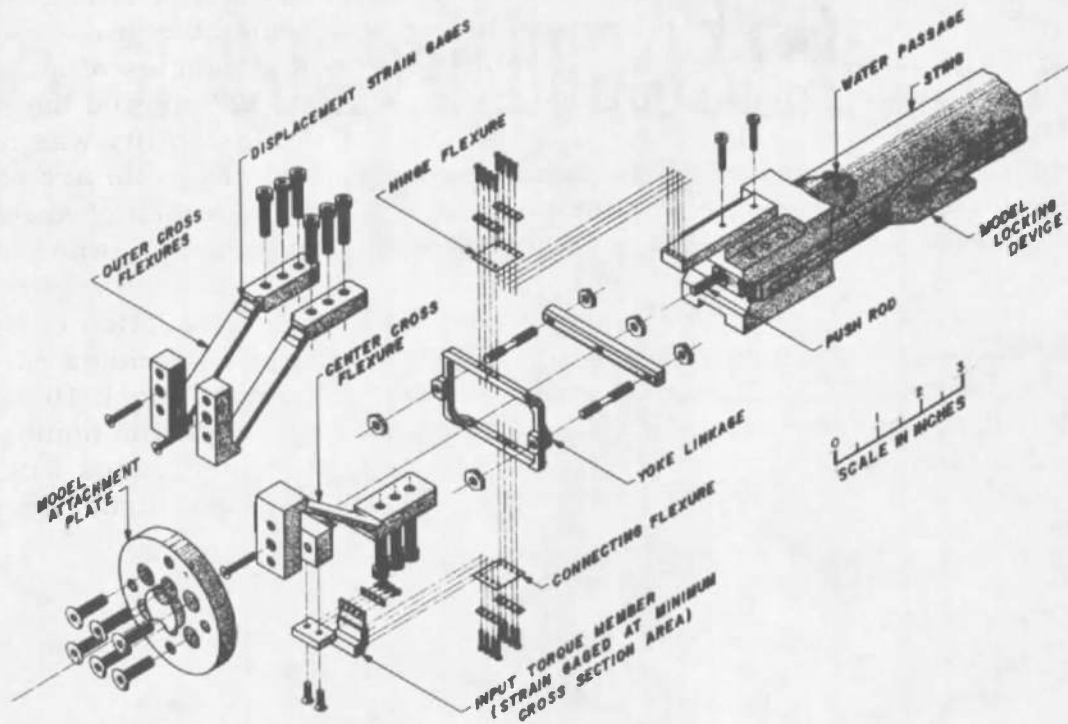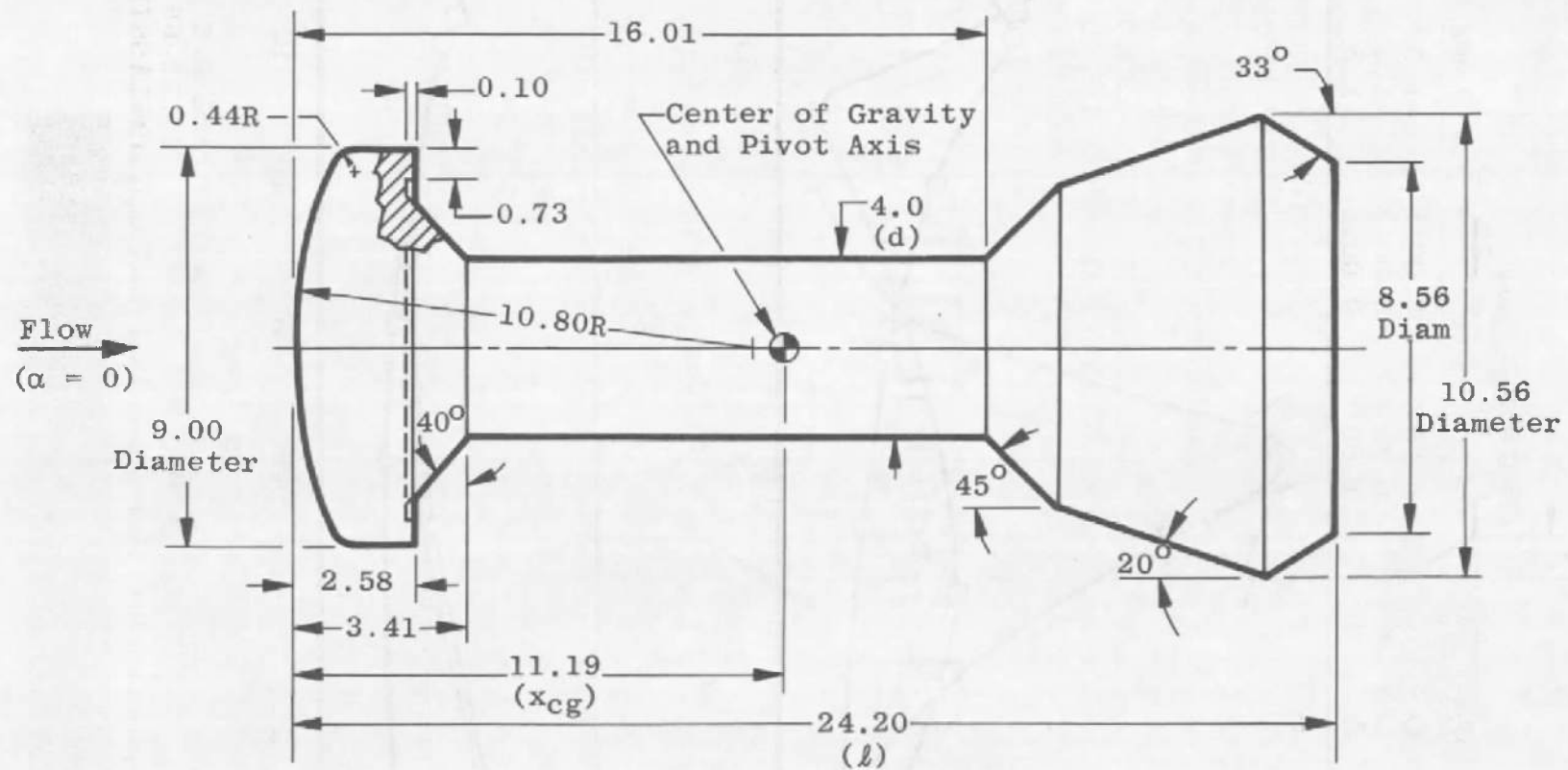
Fig. 1 Small Amplitude (±3-deg), Forced Oscillation Balance

Fig. 2 Photograph of the Model

Fig. 3 Model Geometry

All Dimensions in Inches
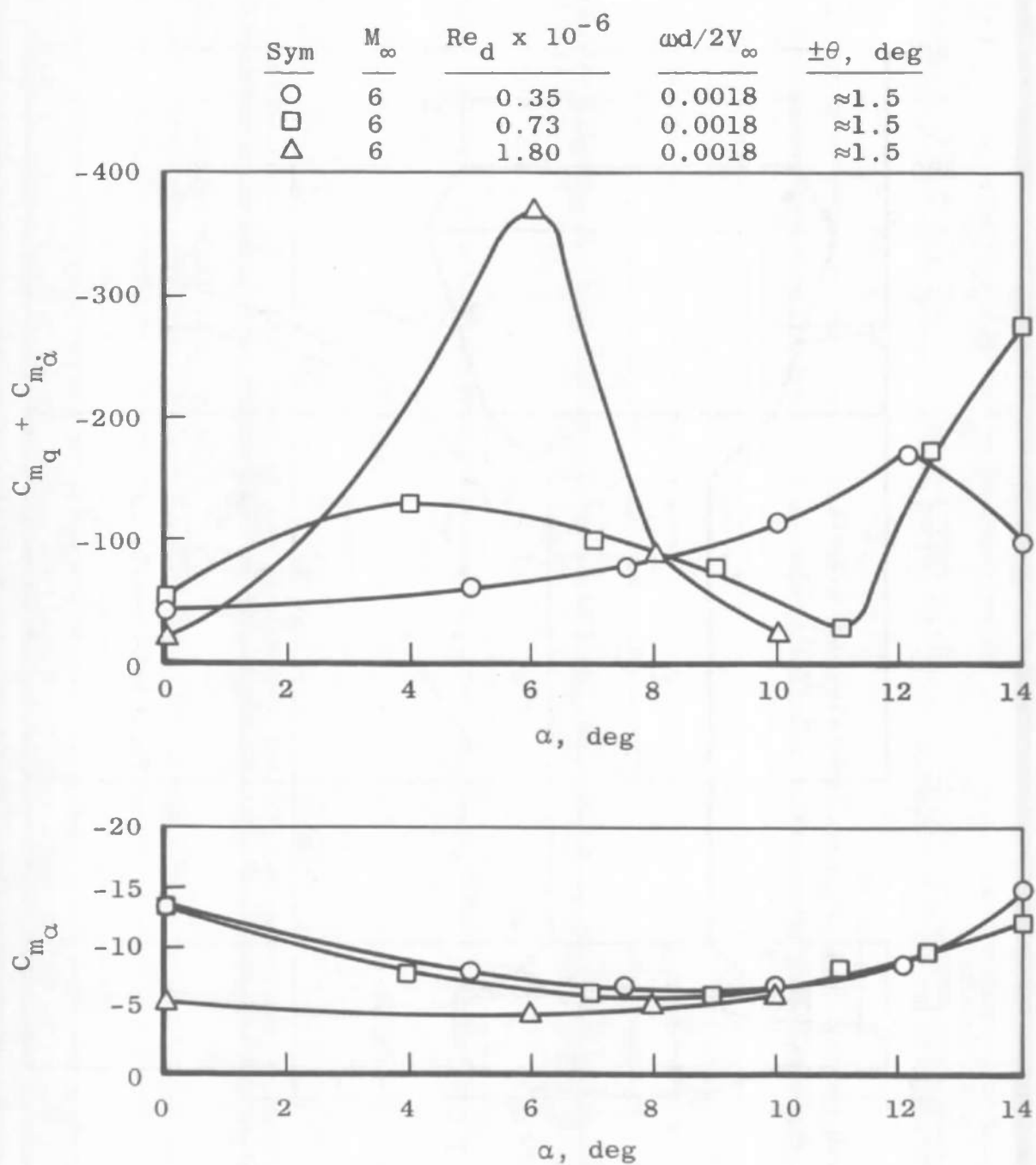
a. $M_\infty = 6$

Fig. 4 Dynamic and Static Stability Derivatives versus Angle of Attack

Sym	M_∞	$Re_d \times 10^{-6}$	$\omega d/2V_\infty$	$\pm\theta$, deg
○	10	0.34	0.0010	≈1.7
□	10	0.58	0.0010	≈1.7
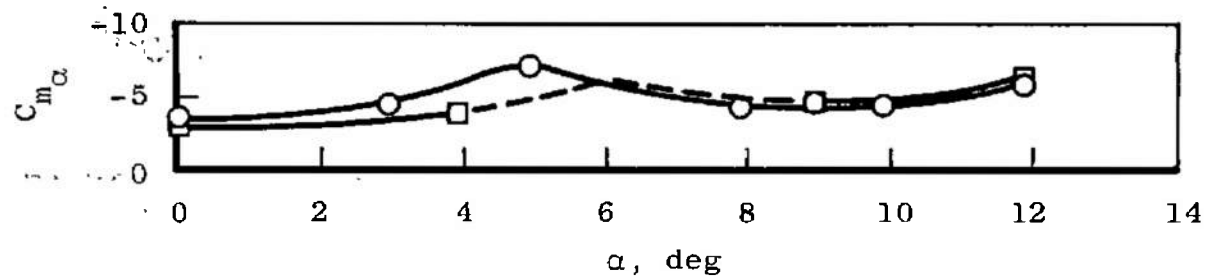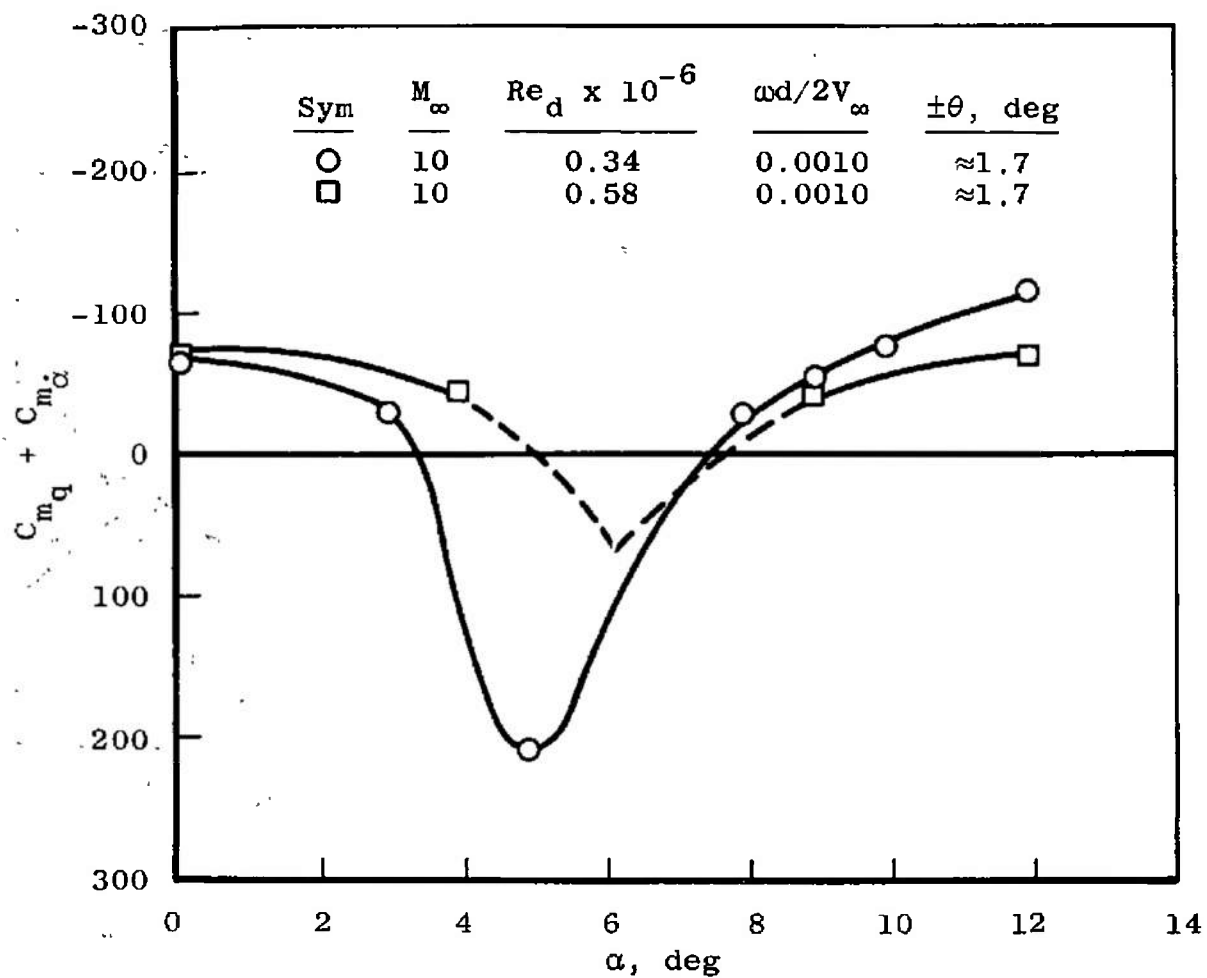
b. $M_\infty = 10$

Fig. 4 Concluded

Fig. 5 Dynamic and Static Stability Derivatives versus Reynolds Number, $\alpha = 0$

TABLE I
SUMMARY OF TEST CONDITIONS

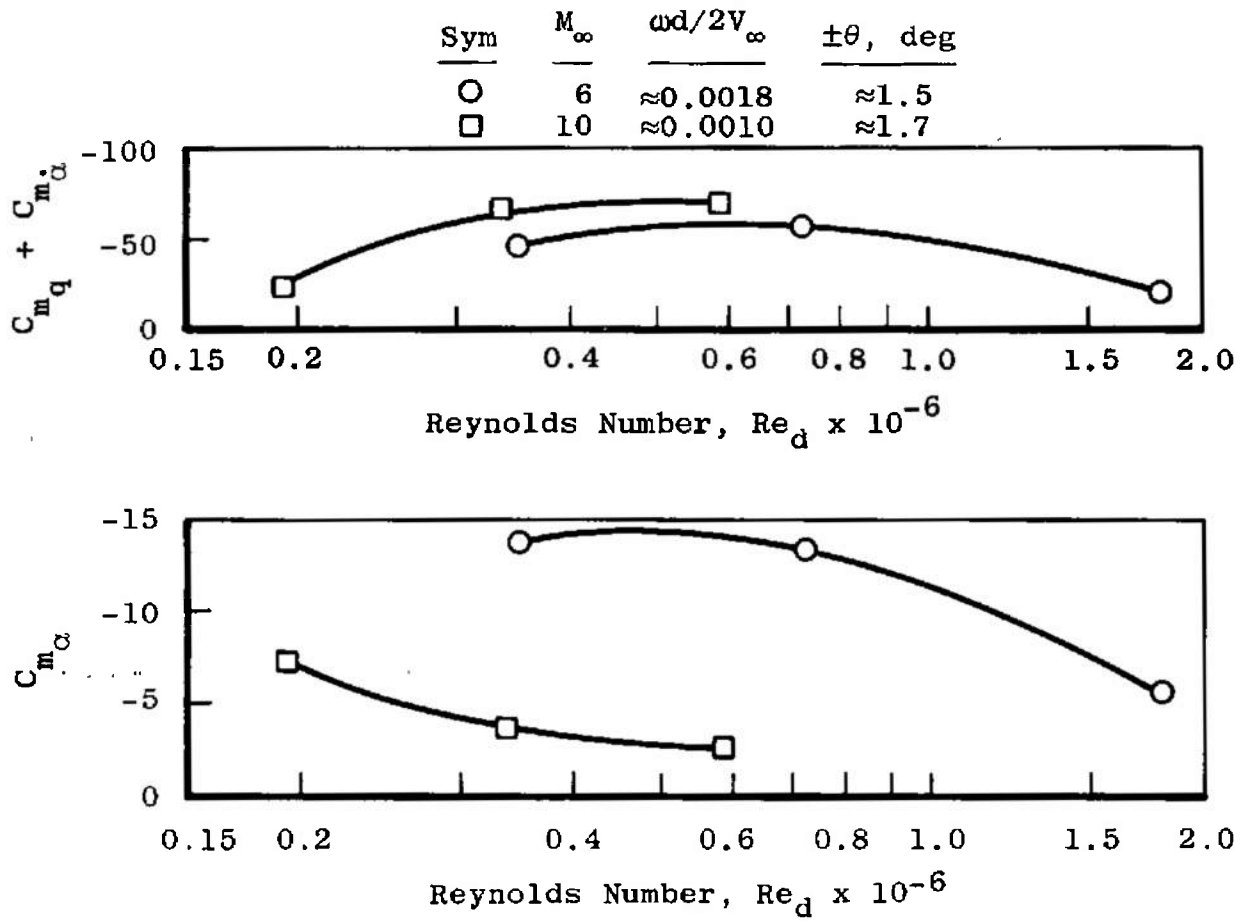| M_∞	$Re_d \times 10^{-6}$	α, deg	$\pm\theta$, deg
6	0.35	0 → 14	≈1.5
6	0.73	0 → 14	≈1.5
6	1.80	0 → 10	≈1.5
10	0.19	0	≈1.7
10	0.34	0 → 12	≈1.7
10	0.58	0 → 12	≈1.7

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)	2a REPORT SECURITY CLASSIFICATION
Arnold Engineering Development Center, ARO, Inc., Operating Contractor, Arnold Air Force Station, Tennessee	UNCLASSIFIED
	2b GROUP N/A

3 REPORT TITLE

DYNAMIC STABILITY TESTS ON THE SNAP-27 FUEL CASK CONFIGURATION AT MACH NUMBERS 6 AND 10

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

N/A

5 AUTHOR(S) *(Last name, first name, initial)*

Uselton, B. L., ARO, Inc.

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
August 1966	18	3

8a CONTRACT OR GRANT NO AF40(600)-1200	9a ORIGINATOR'S REPORT NUMBER(S)
b AEC Activity No. 04.30-01-41.3	AEDC-TR-66-154
c	9b OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d	N/A

10 AVAILABILITY/LIMITATION NOTICES Qualified users may obtain copies of this report from DDC, and release to foreign governments or foreign nationals must have prior approval of the Atomic Energy Commission.

11 SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
N/A	Atomic Energy Commission, Sandia Base, Albuquerque, New Mexico

13 ABSTRACT

Tests were conducted in the 40-in. supersonic wind tunnel and the 50-in. Mach 10 wind tunnel (Tunnels A and C) of the von Kármán Gas Dynamics Facility to determine the dynamic stability characteristics of the SNAP-27 fuel cask configuration. These tests were conducted at Mach numbers 6 and 10 using the forced oscillation technique. Data were obtained at angles of attack from 0 to 14 deg for Reynolds numbers, based on centerbody diameter, ranging from 0.19×10^6 to 1.80×10^6.

DD FORM 1 JAN 64 **1473**

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. SNAP-27 fuel barrels configurations forced oscillation dynamic stability hypersonic flow						

(handwritten annotations: "15 - 14 -", "3 nuclear reactors — Snap 27", and signature)

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through

_____ ."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through

_____ ."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through

_____ ."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.